



US006989989B2

(12) **United States Patent**
Brasz et al.

(10) **Patent No.:** **US 6,989,989 B2**
(45) **Date of Patent:** **Jan. 24, 2006**

- (54) **POWER CONVERTER COOLING**
- (75) Inventors: **Joost J. Brasz**, Fayetteville, NY (US);
Bruce P. Biederman, West Hartford, CT (US)
- (73) Assignee: **UTC Power LLC**, South Windsor, CT (US)
- (*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 111 days.

| | | | |
|----------------|---------|------------------|----------|
| 5,761,921 A | 6/1998 | Hori et al. | |
| 5,809,782 A | 9/1998 | Bronicki et al. | |
| 5,835,362 A * | 11/1998 | Keller et al. | 363/37 |
| 5,860,279 A | 1/1999 | Bronicki et al. | |
| 6,009,711 A | 1/2000 | Kreiger et al. | |
| 6,101,813 A | 8/2000 | Sami et al. | |
| 6,219,245 B1 * | 4/2001 | Nagashima et al. | 361/705 |
| 6,279,336 B1 * | 8/2001 | Grundl et al. | 62/259.2 |
| 6,393,853 B1 * | 5/2002 | Vukovic et al. | 62/259.2 |
| 6,404,631 B1 * | 6/2002 | Lee et al. | 361/699 |
| 6,497,090 B2 | 12/2002 | Bronicki et al. | |
| 6,539,718 B2 | 4/2003 | Bronicki et al. | |

(21) Appl. No.: **10/463,045**

(Continued)

(22) Filed: **Jun. 17, 2003**

FOREIGN PATENT DOCUMENTS

(65) **Prior Publication Data**

DE 19630559 1/1998

US 2004/0257840 A1 Dec. 23, 2004

(Continued)

- (51) **Int. Cl.**
H05K 7/20 (2006.01)
H02J 3/00 (2006.01)
- (52) **U.S. Cl.** **361/699**; 361/702; 363/34
- (58) **Field of Classification Search** 363/34, 363/37, 141; 361/688, 690-693, 698, 699, 361/701, 702, 707, 709, 711; 62/259.2, 263
See application file for complete search history.

OTHER PUBLICATIONS

Thermodynamics of Waste Heat Recovery in Motor Ships, Professor A.J. Morton, MSc, Manchester University, Mechanical Engineering Dept., Trans I Mar E (C), 1981, vol. 93, Paper C69, pp. 1-7.

Primary Examiner—Matthew V. Nguyen
(74) *Attorney, Agent, or Firm*—Wall Marjama & Bilinski LLP

(56) **References Cited**

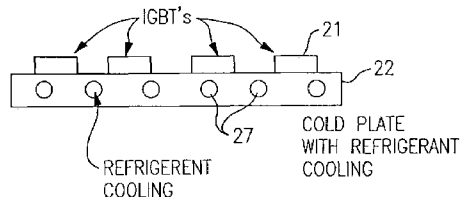
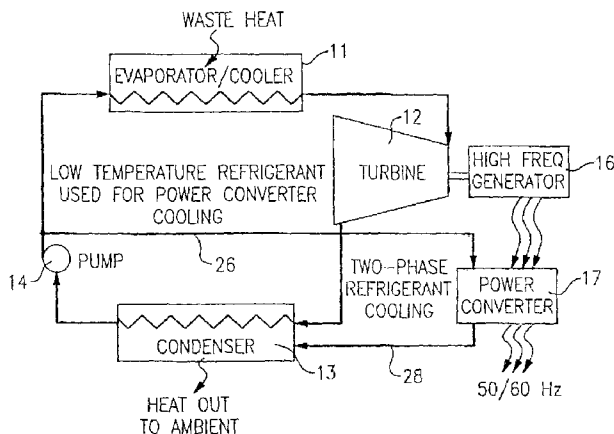
(57) **ABSTRACT**

U.S. PATENT DOCUMENTS

| | | | |
|---------------|---------|-----------------|---------|
| 4,142,231 A * | 2/1979 | Wilson et al. | 363/141 |
| 4,386,499 A | 6/1983 | Raviv et al. | |
| 4,590,384 A | 5/1986 | Bronicki | |
| 4,617,808 A | 10/1986 | Edwards | |
| 4,760,705 A | 8/1988 | Yogev et al. | |
| 4,901,531 A | 2/1990 | Kubo et al. | |
| 5,038,567 A | 8/1991 | Mortiz | |
| 5,119,635 A | 6/1992 | Harel | |
| 5,339,632 A | 8/1994 | McCrabb et al. | |
| 5,598,706 A | 2/1997 | Bronicki et al. | |
| 5,632,143 A | 5/1997 | Fisher et al. | |
| 5,640,842 A | 6/1997 | Bronicki | |
| 5,664,419 A | 9/1997 | Kaplan | |

A power conversion system which uses a plurality of transistors to convert DC power to AC power is made more efficient by the use of liquid refrigerant to cool the transistors. A plurality of passages are formed in a cold plate on which the transistors are mounted, and liquid refrigerant is flashed into the passages to cool the cold plate and the transistors. The liquid refrigerant can be derived from a condenser from an organic rankine cycle or a vapor compression cycle.

16 Claims, 4 Drawing Sheets



US 6,989,989 B2

Page 2

U.S. PATENT DOCUMENTS

6,539,720 B2 4/2003 Rouse et al.
6,539,723 B2 4/2003 Bronicki et al.
6,571,548 B1 6/2003 Bronicki et al.
2002/0148225 A1 10/2002 Lewis
2003/0029169 A1 2/2003 Hanna et al.
2003/0089110 A1 5/2003 Niikura et al.
2003/0167769 A1 9/2003 Bharathan et al.

FOREIGN PATENT DOCUMENTS

DE 19907512 8/2000
DE 10029732 1/2002
EP 1243758 9/2002
JP 52046244 4/1977
JP 54045419 4/1979
JP 54060634 5/1979
JP 55091711 7/1980
JP 58088409 5/1983

JP 58122308 7/1983
JP 59043928 3/1984
JP 59054712 3/1984
JP 59063310 4/1984
JP 59138707 8/1984
JP 59158303 9/1984
JP 60158561 8/1985
JP 06088523 3/1994
JP 2002266655 9/2002
JP 2002285805 10/2002
JP 2002285907 10/2002
JP 2003161101 6/2003
JP 2003161114 6/2003
WO 98/06791 2/1998
WO 02/099279 12/2002
WO 03/078800 9/2003

* cited by examiner

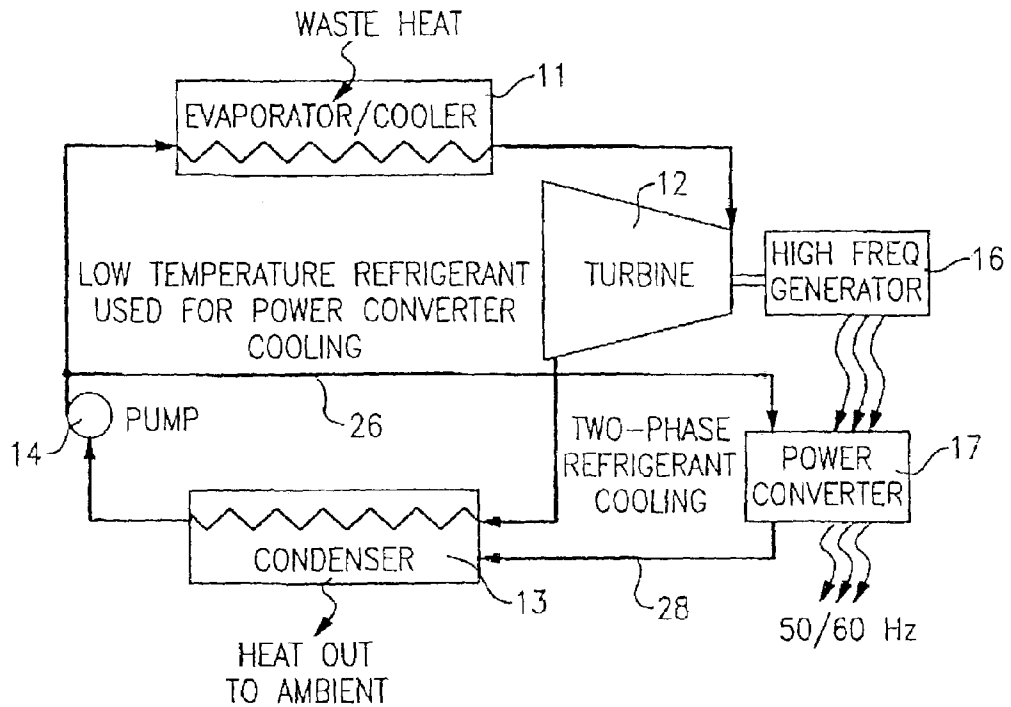


FIG.1

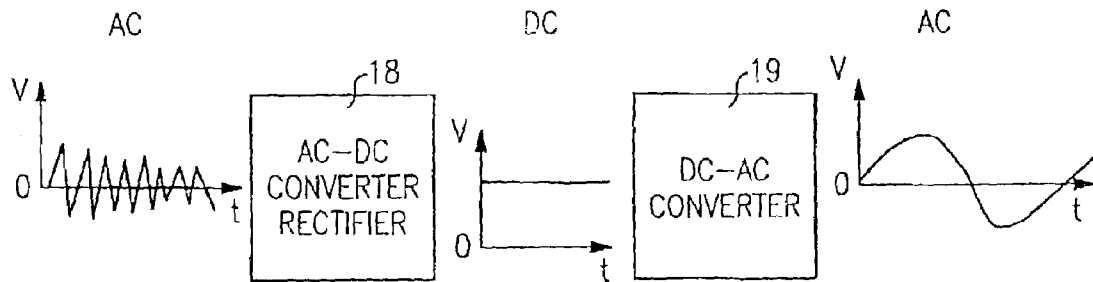


FIG.2
Prior Art

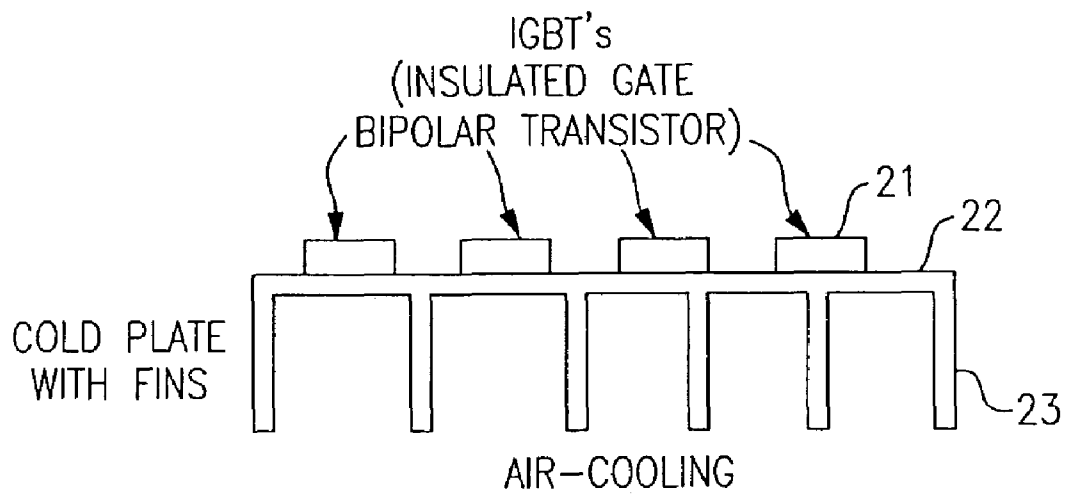


FIG.3
Prior Art

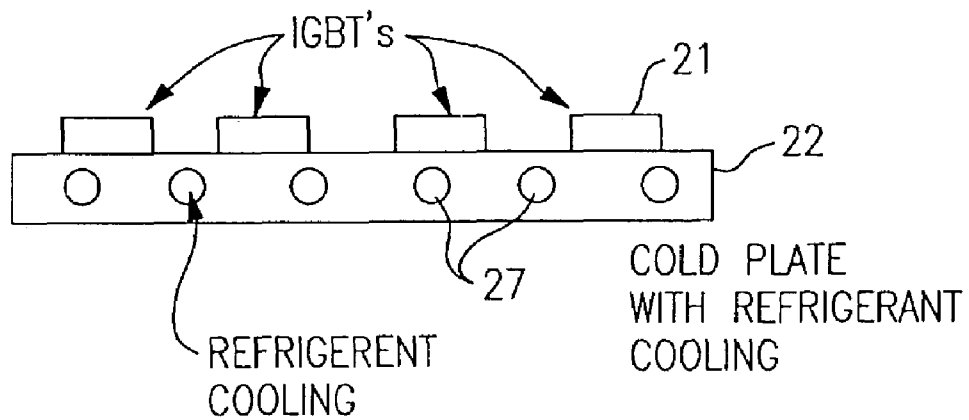
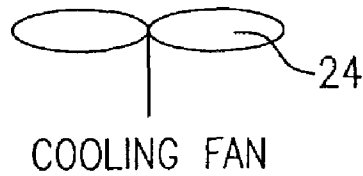


FIG.4

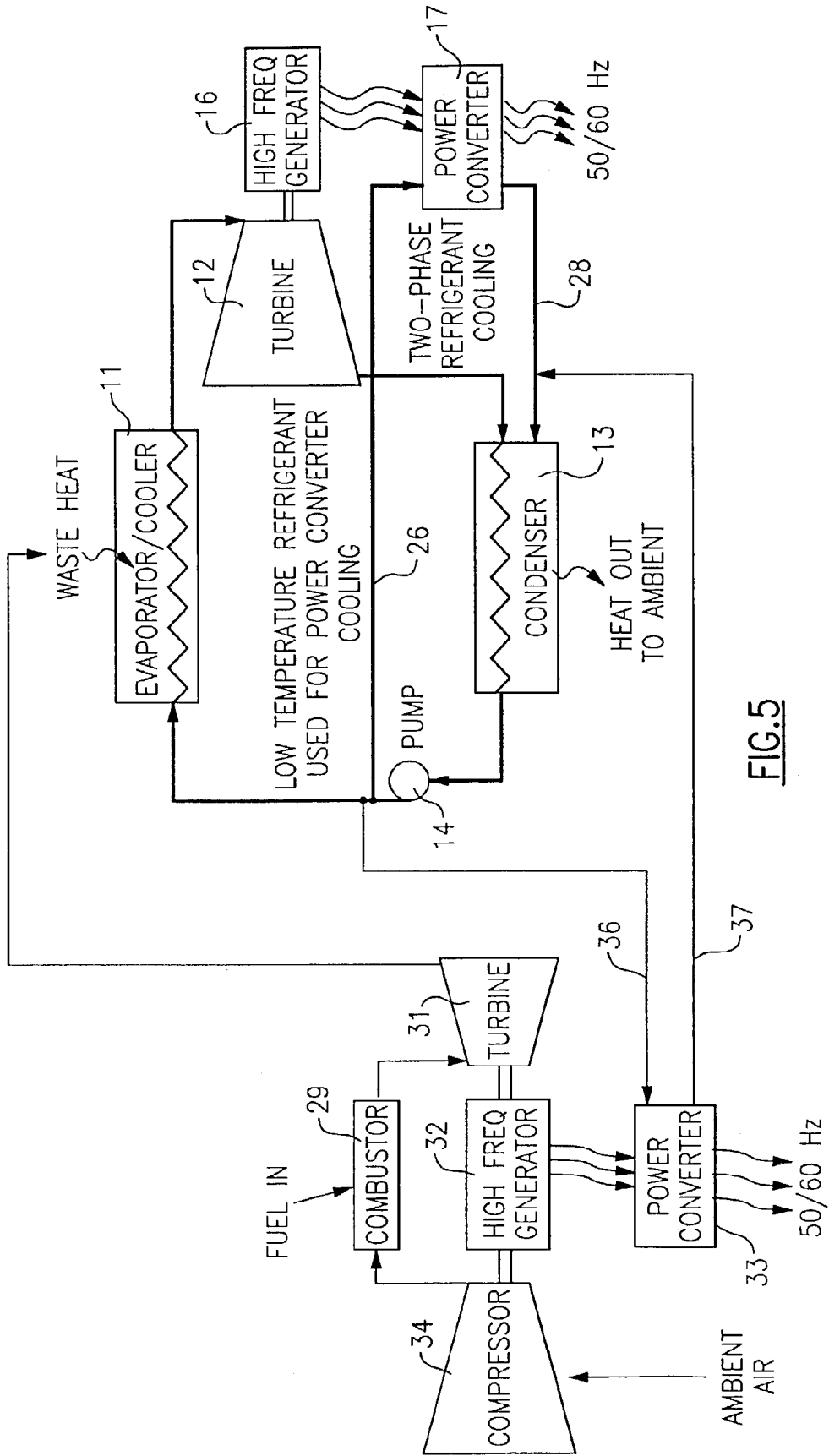


FIG. 5

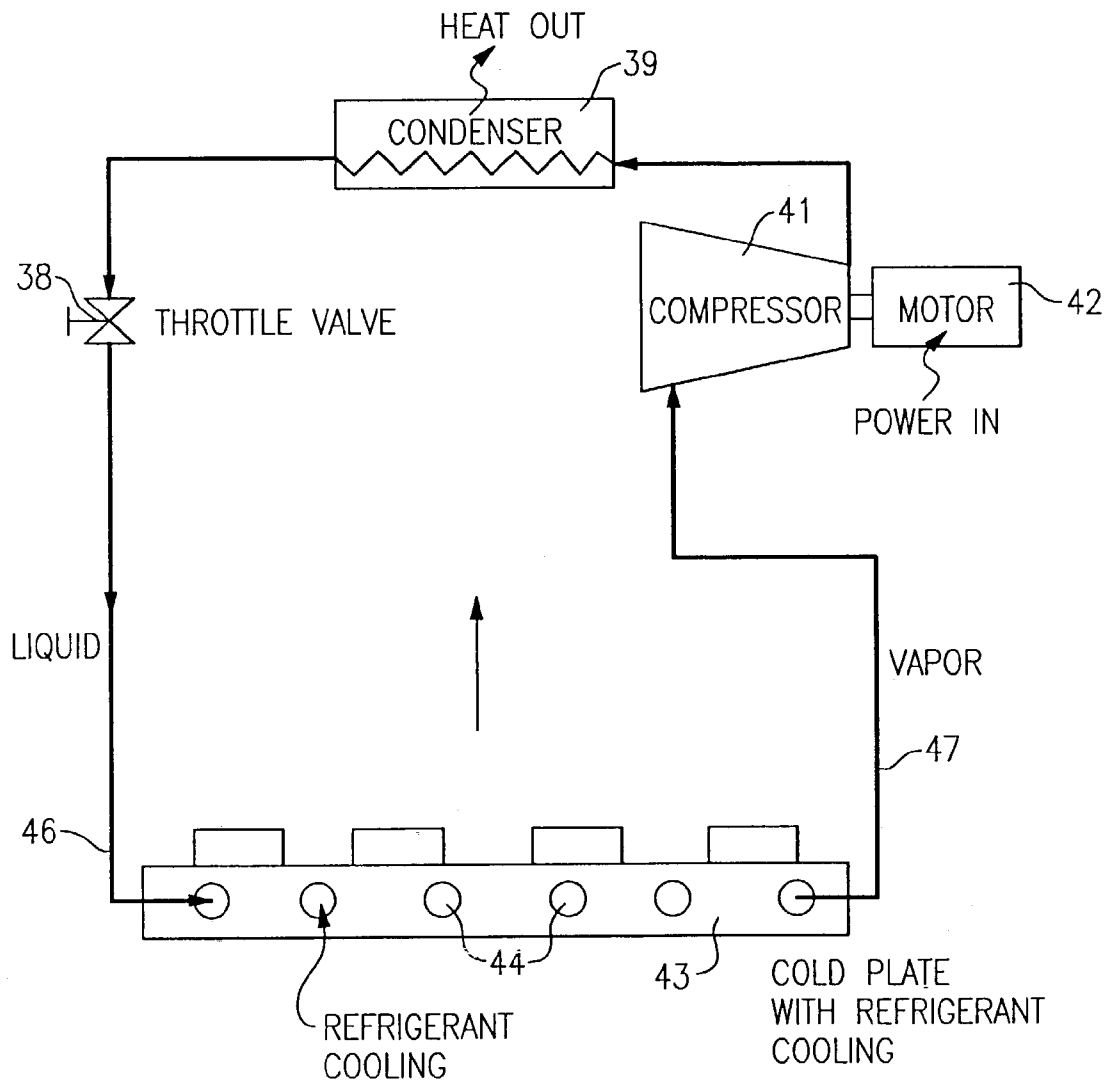


FIG.6

POWER CONVERTER COOLING**BACKGROUND OF THE INVENTION**

This invention relates generally to power conversion systems and, more particularly, to a method and apparatus for cooling power converters.

In the power generation industry, high speed generators are used to generate electrical power at relatively high frequencies (typically a number of times higher than the grid frequency), and power converters are used to convert the high frequency AC power down to an AC grid frequency of 50 or 60 Hz. This is accomplished by rectifying the high frequency AC signal and then generating a new sinusoidal AC wave of the desired frequency. The creation of the new wave involves the use of integrated gate bipolar transistors (IGBT's), which are switched at a carrier frequency rate, which is an order of magnitude higher than the power converter output frequency. Because of the necessary repeated on and off switching of the IGBT's, they generate a substantial amount of heat which must be dissipated. Without cooling this dissipated heat, the temperatures of solid state junctions in the IGBT's would exceed the maximum values, and the transformers would be permanently damaged. Accordingly, all high frequency power conversion equipment typically applies some type of cooling in order to control these junction temperatures.

The cooling requirement increases with power capacity in the IGBT's, and, at a given switching frequency, as the amount of current going through an IGBT is decreased, the heat that is developed will be decreased. Accordingly if the temperature of the solid state junction can be reduced, then the current being switched on and off through the junction can be increased to thereby enhance the power density of the power converter. Further, acceptable IGBT lifetime can be assured if the temperature of the solid state junction is kept below a certain maximum value.

Progress has been made in IGBT design to enable forced-convection air-cooled finned cold plates in removing the heat from the transistors. However, forced-convection air-cooling of finned cold plates is relatively ineffective due to the poor heat transfer between the cooling air and the finned cold plate.

It is therefore an object of the present invention to provide an improved cooling method and apparatus for a power converter.

Another object of the present invention is the provision in a power converter for more effectively cooling the transistors therein.

Another object of the present invention is the provision in a power converter for reducing the temperature of the solid state junctions while increasing the current flow therein.

Yet another object of the present invention is to improve the life of transistors in power conversion systems.

Still another object of the present invention is the provision for a power conversion system that is economical to manufacture and effective and efficient in use.

These objects and other features and advantages become more readily apparent upon reference to the following description when taken in conjunction with the appended drawings.

SUMMARY OF THE INVENTION

Briefly, in accordance with one aspect of the invention, liquid refrigerant is used to reduce the temperature of the transistors and increase the current flow therethrough.

In accordance with another aspect of the invention, liquid refrigerant is caused to flow through internal channels of a cold plate on which the insulated gate bipolar transistors are mounted. In this way, the heat from the transistors is more effectively dissipated such that the transistors can carry greater currents and operate more efficiently.

By yet another aspect of the invention, the liquid refrigerant is taken from the discharge of a pump in an organic rankine cycle system and is routed to a power converter receiving the output of a high frequency generator driven by the organic rankine cycle turbine.

By yet another aspect of the invention, the liquid refrigerant is taken from the discharge of a pump in an organic rankine cycle system and routed to a power converter receiving its electrical power from a generator driven by a microturbine.

By still another aspect of the invention, the liquid refrigerant is taken from the condenser of a conventional vapor compression cycle, and is allowed to expand into the cold plate, after which the resulting vapor is caused to flow back to the compressor of the vapor compression cycle.

In the drawings as hereinafter described, a preferred embodiment is depicted; however, various other modifications and alternate constructions can be made thereto without departing from the true spirit and scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an organic rankine cycle power generation system in accordance with the present invention.

FIG. 2 is a schematic illustration of the function of a power converter in accordance with the prior art.

FIG. 3 is a schematic illustration of the cooling of a power converter in accordance with the prior art.

FIG. 4 is a schematic illustration of the cooling arrangement for a power converter in accordance with the present invention.

FIG. 5 is a schematic illustration of the cooling of a power converter in a microturbine system in accordance with the present invention.

FIG. 6 is a schematic illustration of the cooling of a power converter with a conventional vapor compression cycle in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, a rankine cycle system is shown to include an evaporator/cooler 11, a turbine 12, a condenser 13 and a pump 14 arranged for the serial flow of refrigerant therethrough as shown by the arrows.

The evaporator/cooler 11 is commonly a boiler having a significant heat input, and the energy source that is applied as waste heat can be of any form of waste heat that may normally be lost to the atmosphere. For example, it may be a small gas turbine engine (<500 kw), known as a micro-turbine or a larger industrial gas turbine engine (>500 kw). In either case, the heat is derived from the exhaust gas thereof. Other possible sources of waste heat are from the exhaust gases and/or cooling liquids from internal combustion engines. Finally, the energy may be derived from geothermal sources or from landfill flare exhausts wherein the hot fluids are applied directly to the boiler to produce refrigerant vapor or applied indirectly by first using those resource fluids to drive an engine which, in turn, gives off heat which can be used as described hereinabove.

In operation, the evaporator/cooler **11** vaporizes the refrigerant which then passes to the turbine **12** for providing motive power thereto. Upon leaving the turbine **12**, the low pressure vapor passes through the condenser **13** where it is condensed by way of heat exchange relationship with a cooling medium. The cooled condensed liquid is then pressurized and circulated to the evaporator/boiler by a pump **14** to complete the cycle.

Drivingly connected to the turbine **12** is a high frequency generator **16**. In order to be efficient, the turbine **12** must operate at high speeds, and preferable the generator **16** is connected in a direct drive relationship such that the generator **16** must also operate at relatively high speeds. As a result, and as desired for greatest efficiency, the power generated by the high frequency generator **16** is typically a number of times greater than the frequency of the grid (i.e. 50 or 60 Hz) that is to receive the generated power. It is therefore necessary to provide a power converter **17** to convert the high frequency power to a lower frequency power that can be applied directly to the grid.

Referring to FIG. 2, there is shown a functional diagram of what occurs within the power converter **17**. Briefly, the high frequency AC signal is passed through one or more rectifiers **18** that convert the power to DC, and then the DC signal is fed to an inverter **19** which generates the new sinusoidal AC wave of the desired low frequency.

The inverter function is accomplished by the sequential operation of a great number of switching mechanisms commonly referred to as IGBT's (insulated heat bipolar transistors). Because of the required rapid switching operation, the IGBT's tend to generate a great deal of heat which, if not dissipated, will quickly burn out the transistors. It has therefore become conventional practice to mount the IGBT's **21** on a cold plate **22** having a plurality of cooling fins **23** as shown in FIG. 3. In order to dissipate the heat from the cold plate **22** a cooling fan **24** is directed to circulate cool air over the fin **23**. Although effective, this approach has been recognized by the applicants as inadequate in providing the degree of cooling that is desirable in order to allow for the desired power densities in the power converter **17**.

Referring again to FIG. 1, it will be seen that at the output of the pump **14** a relatively high pressure cold refrigerant is readily available and can be effectively used in the cooling of the power converter components. A line **26** is therefore provided to conduct a relatively small amount of cold, high pressure, liquid refrigerant to the power converter **17** where it is expanded into a plurality of internal openings **27** of the cold plate **22** as shown in FIG. 4. The flashing of the refrigerant into the cold plate **22** quickly and substantially reduces the temperature of the cold plate, which is in contact with the IGBT's **21**, and reduces the IGBT solid state junction temperature dramatically, e.g. by 50 to 100° F. depending on the design. This, in turn, allows more current to be passed through the IGBT's, such that the power switching capacity of the solid state hardware increases substantially thereby increasing the power density by 50 to 100%, thus reducing the cost of power conversion equipment by the same percentage.

After the refrigerant passes through the cold plate **27** the resulting refrigerant vapor is passed along through the condenser **13** by way of line **28** as shown in FIG. 1.

Referring now to FIG. 5, another embodiment of the present invention is shown to include not only the organic rankine cycle system as described hereinabove, but also a microturbine that can be used in combination with the organic rankine cycle system. For example, the microturbine may burn natural gas or landfill methane gas in its combus-

tion chamber, and with use of the turbine, convert that energy into electrical energy which may be transferred to the grid. In turn, the exhaust from the microturbine may be used to heat the boiler **11** of the organic rankine cycle system.

The microturbine system as shown in the left side of FIG. 5 includes a burner or combustor **29**, a turbine **31**, and a generator **32** which operate in much the same manner as the turbine and the generator in the organic rankine cycle system as described hereinabove. Further, the power generated by the generator **32** is typically of the high frequency type as described hereinabove such that it is necessary to pass it through a power converter **33** to convert the power to a lower frequency form that can be assimilated into the grid.

The gas turbine requires compression of ambient air and fuel (e.g. natural gas or methane) prior to ignition in the burner **29**. This is accomplished by a compressor **34** which is driven by the shaft that is common to the generator **32** and the turbine **31**.

The power converter **33** is of the same type as the power converter **17**, and the cooling arrangement as shown in FIG. 4 is substantially the same, with liquid refrigerant passing along line **36** to the cold plate of the power converter **33**, and the refrigerant vapor then passing back to the condenser **15** by way of line **37**.

So far the present invention has been described in terms of use of liquid refrigerant from an organic rankine cycle system, that is diverted to a power converter for cooling the components therein. However, it should be recognized that this source of liquid refrigerant can come from other types of apparatus such as that as shown in FIG. 6. Here, a rather conventional vapor compression system is shown to include a throttle valve **38**, a condenser **39** and a compressor **41** driven by a motor **42**. However, rather than an evaporator that is part of a conventional vapor compression system, the cold plate **43** of a power converter, having openings **44** for the flow of refrigerant is connected in as part of the cycle. Thus, liquid refrigerant flows along lines **46** from the throttle valve **38** to the cold plate **43** where it is expanded to cool the cold plate **43**. The resulting refrigerant vapor then flows from the cold plate **43**, along lines **47** to the compressor **41**.

The cooling requirement of a power converter is around 3% of the power being converted. A typical air cooled air conditioning device having a coefficient of performance of around 3, will therefore need only 1% of the power generated to perform the cooling thus doubling the power density or capacity of the power converter.

The vapor compression system as shown in FIG. 6 is a relatively small system on the order of a room air conditioner for a 200 kw microturbine, and can be easily and economically adapted for use to cool a power converter and in doing so will substantially increase its power capacity so as to being about substantial economic gains.

While the present invention has been particularly shown and described with reference to preferred and alternate embodiments as illustrated in the drawings, it will be understood by one skilled in the art that various changes and detail may be effected therein without departing from the true spirit and scope of the invention as defined by the claims.

We claim:

1. A power conversion system for converting electrical power from a high frequency level to a lower frequency level comprising:

means for rectifying the power of a high frequency AC source to create a direct current;

means for converting said DC current to AC current of a lower frequency than that of said AC source, said

5

converting means including a plurality of switching mechanisms mounted in heat exchange relationship with a cold plate; and

liquid refrigerant circulation means for circulating liquid refrigerant through said cold plate to provide cooling thereof

wherein said liquid refrigerant is obtained from a condenser in a closed circuit system.

2. A power conversion system as set forth in claim 1 said switching mechanisms comprise transistors.

3. A power conversion system as set forth in claim 2 wherein said transistors comprise insulated gate bipolar transistors.

4. A power conversion system as set forth in claim 1 wherein said liquid refrigerant circulation means includes a plurality of passages in said cold plates.

5. A power conversion system as set forth in claim 1 wherein said closed circuit system is a vapor compression cycle.

6. A power conversion system as set forth in claim 1 wherein said power is derived from a generator driven by a turbine in an organic rankine cycle system.

7. A power conversion system as set forth in claim 1 wherein said power is derived from a microturbine.

8. An electrical power generating system comprising: a turbine for receiving a gaseous medium and converting its energy to motive power;

an electrical generator drivingly connected to said turbine for producing AC power at a relatively high frequency;

a power converter connected to said generator for converting said high frequency AC power to lower fre

6

quency AC power with the use of a plurality of switches; and

means for cooling said plurality of switches by circulating liquid refrigerant through a structure on which said switches are mounted.

9. An electrical power generating system as set forth claim 8 wherein said gaseous medium is a refrigerant.

10. An electrical power generating system as set forth in claim 8 wherein said gaseous medium is heated by combustion gases.

11. An electrical power generating system as set forth in claim 8 wherein said plurality of switches are transistors.

12. An electrical power generating system as set forth in claim 11 wherein said transistors comprise insulated gate bipolar transistors.

13. An electrical power generating system as set forth in claim 8 wherein said structure on which said switches are mounted comprises a cold plate.

14. An electrical power generating system as set forth in claim 13 wherein said cold plate has a plurality of passages formed therein.

15. An electrical power generating system as set forth in claim 8 wherein said liquid refrigerant is derived from a condenser in a closed circuit system.

16. An electrical power generating system as set forth in claim 15 wherein said closed circuit comprises a vapor compression system.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,989,989 B2
APPLICATION NO. : 10/463045
DATED : January 24, 2006
INVENTOR(S) : Joost J. Brasz et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 4 line 23 the numeral "**15**" should be numeral --13--


Column 4 line 44 the numeral "**3**" should NOT be in BOLD

Column 4 line 46 "th" should be --the--

Column 5 line 15 "crefrigerant" should be --refrigerant--

Signed and Sealed this

Fifteenth Day of August, 2006

A handwritten signature in black ink on a light gray dotted background. The signature reads "Jon W. Dudas" in a cursive style.

JON W. DUDAS

Director of the United States Patent and Trademark Office